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PREDICTING YEAR-CLASS ABUNDANCE OF YELLOWSTONE LAKE CUTTHROAT TROUT

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RESEARCH REPORT 59

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Ross V. Bulkley and
Norman G. Benson
Fishery Research Biologists

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UNITED STATES DEPARTMENT OF THE INTERIOR
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Frank P. Briggs, *Assistant Secretary for Fish and Wildlife*

FISH AND WILDLIFE SERVICE
Clarence F. Pautzke, *Commissioner*

BUREAU OF SPORT FISHERIES AND WILDLIFE
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ABSTRACT

Fluctuations in strength of year classes from 1945 to 1956 of Yellowstone Lake cutthroat from Pelican and Chipmunk Creeks are compared with the parental stock and several climatically influenced factors of the environment. Variations in year-class strength in the two tributaries were highly correlated with fluctuations in lake water levels. Strong year classes occurred in years of low water. Female spawner escapement, timing of the runs, and summer air temperatures were not significant factors.

A formula based on water levels is presented for predicting year-class strength in Pelican Creek and in the Fishing Bridge area fishery.

Stocking of fry in years of high water is suggested as a means of supplementing natural production. A method of forecasting lake water levels several months in advance of their occurrence is discussed.

PREDICTING YEAR-CLASS ABUNDANCE OF YELLOWSTONE LAKE CUTTHROAT TROUT

By Ross V. Bulkley and Norman G. Benson, *Fishery Research Biologists*

Rocky Mountain Sport Fishery Investigations, Logan, Utah

Large fluctuations occur in year-class strength of cutthroat trout, *Salmo clarki lewisi*, in Yellowstone Lake, Wyoming. The ability to predict the occurrence of these fluctuations is of great value in managing the fishery. This paper discusses five factors suspected of controlling year-class strength in Pelican and Chipmunk Creeks, two large tributaries of Yellowstone Lake, and the use of these factors to predict future recruitment to the fishery.

Pelican Creek is one of the major spawning streams in the north end of Yellowstone Lake (fig. 1). Terminal water flow in August is around 40 cubic feet per second, but the flow is several times as large during the spring high-water period. The Pelican Creek drainage contains approximately 100 miles of stream available for spawning. Adult fish move into the stream during May, June, and early July for spawning, and return to the lake after spawning. A few spawners overwinter in the stream. Many fry remain in the stream during their first winter and move down to the lake in their second and third years of life. Recruitment to the spawning runs occurs during the fourth and fifth years of life.

Chipmunk Creek enters Yellowstone Lake at the lower end of the south arm. Terminal stream flow during August is around 25 cubic feet per second. The spring runoff is more gradual than Pelican Creek, and is relatively free of debris. Spawning runs in Chipmunk Creek are bimodal, commencing in May and extending to the end of July (Cope, 1957b). Most spawning occurs in the lower 8 miles of the stream, and the majority of the fry move downstream to the lake during their first summer. Initial spawners in this stream are fish of age groups III, IV, and V; some fish from Chipmunk Creek do not mature until their sixth year of life (Bulkley, 1961). In both streams, larger and older spawners are most abundant in the early part of each spawning run, and smaller spawners are most abundant in the latter part of each run.

Counts of spawners and collections of scales were made from Pelican and Chipmunk Creeks spawning runs from 1949 to 1960. Scale samples and measurements were taken from 10 percent of each run. Data from upstream traps near the mouth of each stream provided information on the time and size of the spawning migrations. Scale samples from the fishery were obtained periodically during the summer from 1950 to 1960 at Fishing Bridge and West Thumb docks. Fish from Pelican Creek are commonly caught in the Fishing Bridge area, as this stream enters the lake 1 mile from the Fishing Bridge campground (Ball and Cope, 1961). Chipmunk Creek fish contribute to the West Thumb fishery, but the percentage of the West Thumb catch that comes from fish produced in that stream is not known.

Scales were aged according to criteria established by Laakso and Cope (1956) for identification of fish which fail to form the initial annulus on their scales. Cutthroat

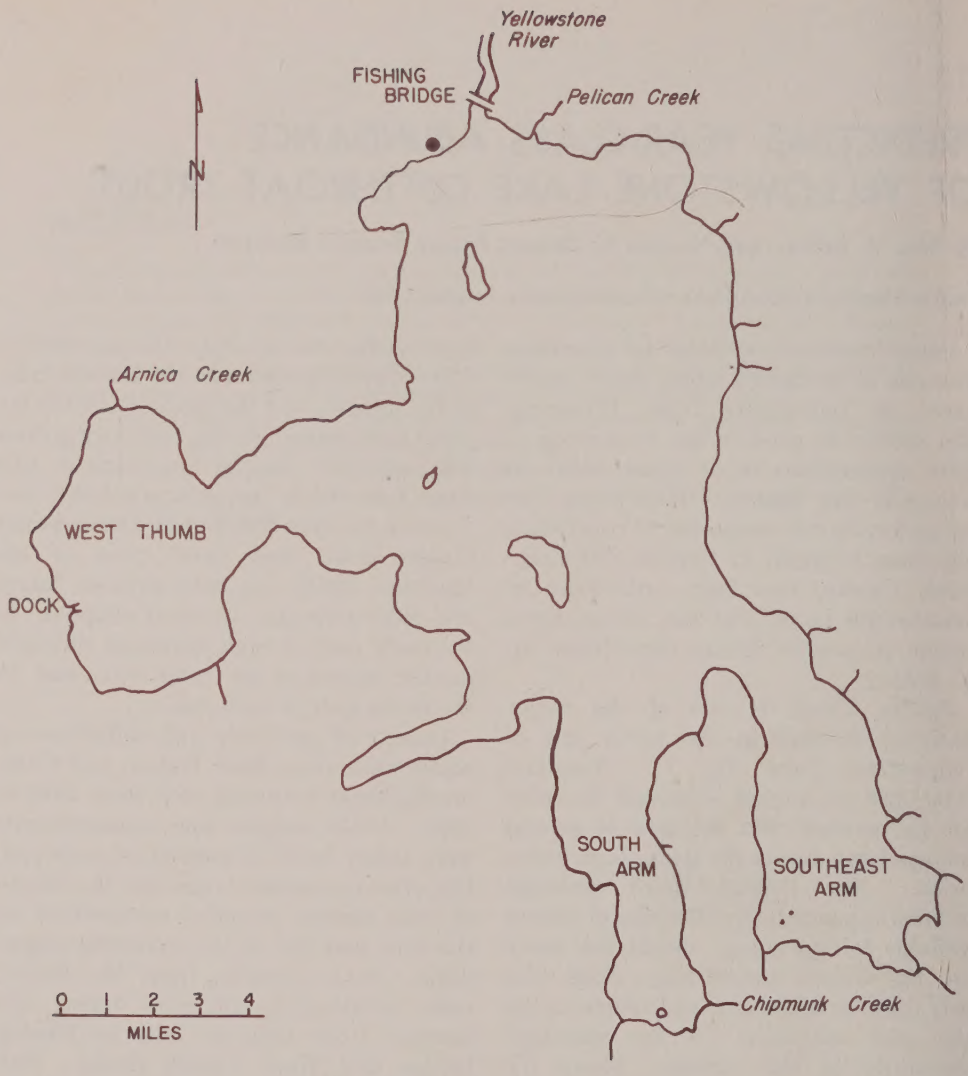

FIGURE 1.—Yellowstone Lake showing location of two study streams. The area where water levels and air temperature were recorded is indicated by closed circle near Fishing Bridge.

trout with retarded scale development are relatively common in Yellowstone Lake.

Daily gage heights of Yellowstone Lake at the Lake Hotel were obtained from reports of the U.S. Geological Survey. Daily air temperatures at the Lake Ranger Station were obtained from U.S. Weather Bureau reports. Data used in this paper on the lake water levels and on air temperatures are summarized in appendix A.

Drs. W. E. Ricker, George A. Rounsefell Oliver B. Cope, and Mr. Bernard E. Skud critically reviewed the manuscript and offered several excellent suggestions for its improvement. Messrs. Ashton R. Codd and Phillip E. Farnes of the Soil Conservation Service provided the forecasts of Yellowstone Lake water levels.

YEAR-CLASS STRENGTH

Estimates of year-class strength were determined from the number of fish of both sexes assumed to be initial spawners returning to the parent stream from each year class. Fish of age groups III and IV were used for Pelican Creek; fish of age groups III, IV, and V were used for Chipmunk Creek. A few spawners are undoubtedly counted twice by this method, but spawning mortality is sufficiently high that only a small percentage survive to return as repeat spawners (Ball and Cope, 1961). Most of the spawners which do return require 2 years to recover and come back as alternate spawners. Recruitment of fish to the spawning runs was considered to be a good index of relative year-class strength, as the homing instinct is strong and few fish spawn in streams other than their parent stream (Ball, 1955). The lake fishery is concentrated on the same age groups as found in the spawning runs, and recruitment to the fishery of prespawners was independent of the size of the catch prior to the 1956 year class in Pelican Creek and to the 1955 year class in Chipmunk Creek.[1] Thus, variations in the catch did not seriously alter estimates of year-class strength based on numbers of initial spawners. This method could not be used for Pelican Creek from 1945 to 1947 because 500,000 fry were planted in that stream each year. No fry were planted in Chipmunk Creek after 1944.

Pelican Creek produced large year classes in 1949, 1953, and 1955 (fig. 2). Chipmunk Creek estimates (no data available for 1956) indicate that 1945, 1946, and 1953 were large year classes and the 1951 year class was extremely small. Year-class strength of the two streams is obviously unrelated in some years.

FACTORS COMPARED WITH YEAR-CLASS STRENGTH FLUCTUATIONS

Benson (1960) showed that receding water levels and cloudy weather partially controlled the downstream migrations of immature cutthroat trout in Arnica Creek, a small tributary to Yellowstone Lake, but there was no relation between this migration of immatures and the number of adults returning. As accurate data were not available on stream-level fluctuations and light intensity at Pelican and Chipmunk Creeks, these factors could not be tested in the present study. Factors tested for association with year-class strength in Pelican and Chipmunk Creeks included female spawner escapement, timing of the spawning runs, air temperature, and lake water levels. Pelican Creek anaylses are presented first, with field data for both streams. Results of Chipmunk Creek analyses are presented later for clarity.

Female escapement

The number of spawners producing a year class was one factor suspected of controlling year-class strength A large egg potential under certain conditions could be expected to produce an abundant year class. Escapement of female spawners was compared with estimates of year-class strength to determine whether size of parental stock was controlling year-class strength in the two study streams. Numbers of female spawners were used because the size of male escapement was not recorded before 1954. Escapement of female spawners in Pelican and Chipmunk Creeks fluctuated widely from 1945 to 1956 (table 1). Much of this fluctuation

[1] "Equilibrium yield and management of cutthroat trout in Yellowstone Lake," by Norman G. Benson and Ross V. Bulkley. Manuscript in preparation.

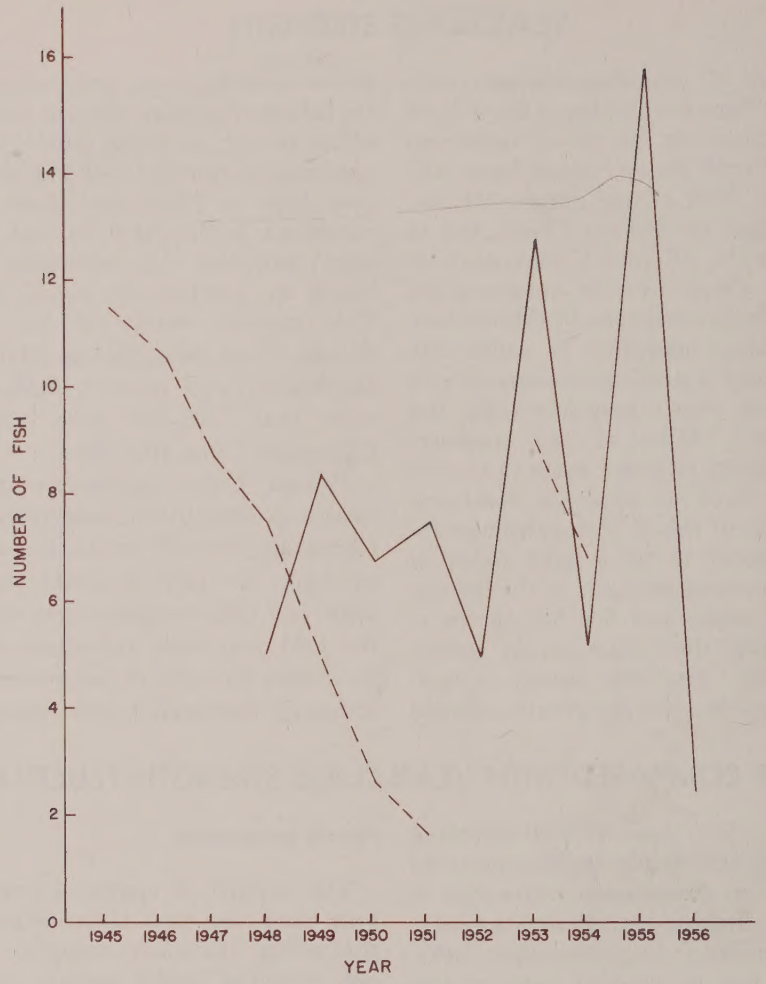

FIGURE 2.—Year-class strength for Pelican (solid line) and Chipmunk Creeks (broken line)—expressed in thousands of fish.

was caused by fish-hatchery operations at Yellowstone Lake, which continued until 1953. Eggs for the hatchery were obtained from wild fish as they ascended the tributaries to spawn. The number of females released for natural spawning depended on the size of the spawning runs and the number of eggs needed by the hatchery each year. As all males not needed for spawn-taking were allowed to continue upstream, there is little reason to suspect that a shortage of males for natural spawning ever occurred. After 1953 all spawners were allowed to spawn naturally.

Analysis of the relation between Pelican Creek female escapement and number of progeny returning to spawn from the year class did not show a significant correlation ($r=0.480$, $d.f.=7$) although the plotted data suggest that a rather strong positive correlation existed (fig. 3). Low female escapement tended to have low production, and high escapement to have high production. The 1949 data

TABLE 1.—*Size of female escapement in Pelican and Chipmunk Creeks and recruitment to future runs from each year class*

Year-class	Female escapement		Recruitment	
	Pelican Creek	Chipmunk Creek	Pelican Creek [1]	Chipmunk Creek [2]
1945		2,331		11,524
1946		6,350		10,665
1947		841		8,838
1948	4,418	2,449	5,032	7,500
1949	14,591	2,650	8,377	5,286
1950	3,381	2,628	6,755	2,729
1951	1,969	[3] 2,398	7,569	
1952	613	1,695	4,985	
1953	7,475	2,711	12,863	9,184
1954	6,438	3,237	5,267	6,921
1955	9,030	2,678	16,023	
1956	[3] 4,166		2,503	

[1] Total fish of age III and IV returning as first spawners from year class.
[2] Total fish of age III, IV, and V returning as first spawners.
[3] Complete count not obtained.

suggest that production falls off as female spawner numbers approach 14,000. The "Ricker Curve" (Ricker, 1958, p. 239), which passes through the origin and falls off asymptotically at high stock levels, seemed to describe the Pelican Creek population but did not reduce the residual variance. The free-hand curve illustrated was fitted to the data with the aid of moving averages of three and may be closer to the true relation. This curve suggests that increased production can be obtained by increasing female escapement up to approximately 9,000 females. Shepard and Withler (1958) described a similar reproduction curve for sockeye salmon. Assuming a continuation of the average sex ratio of Pelican Creek runs of 1.64 females per male (Ball and Cope, 1961), 9,000 females would represent a total spawning run of approximately 14,500 fish. The broken diagonal line in figure 3 is based on the average sex ratio and indicates the level at which replacement occurs. Each female must produce on the average 1.61 adult progeny for the population to maintain the same density. Thus escapement to the right of the diagonal failed to replace itself (1948, 1949, 1954, and 1956) and escapement to the left more than replaced itself.

Data presented later on water levels and the low correlation between female escapement and progeny suggest that escapement is a secondary factor in controlling production within the range of spawners given above. Benson (1960) and Ball and Cope (1961) did not find any correlation between number of spawners and number of progeny produced.

Time of spawning

Timing of spawning runs is frequently considered a possible control of production. Exceedingly early or late segments of the spawning runs are often less successful than the middle part owing to adverse environment (Rounsefell, 1958). Spawning runs in Pelican and Chipmunk Creeks usually start about the same time each year, although there is considerable variation in the time in which one-half of the run passes upstream in different years. The date by which 50 percent of the run entered the upstream trap was compared with the relative strength of the year class which the run produced, to measure the effect of these variations in timing (table 2).

TABLE 2.—*Date by which 50 percent of spawning run entered upstream traps at Pelican and Chipmunk Creeks*

[Expressed as the number of days after May 28]

Year	Pelican Creek	Chipmunk Creek
1945		25
1946	1	4
1947	4	9
1948		12
1949	2	27
1950	21	41
1951	9	
1952	11	
1953	18	13
1954	10	38
1955	11	

Timing of the run apparently did not influence production in Pelican Creek to any extent as a correlation coefficient of 0.115 ($d.f.=5$) was far from significant.

Air temperature

Air temperatures were considered a factor controlling production under the

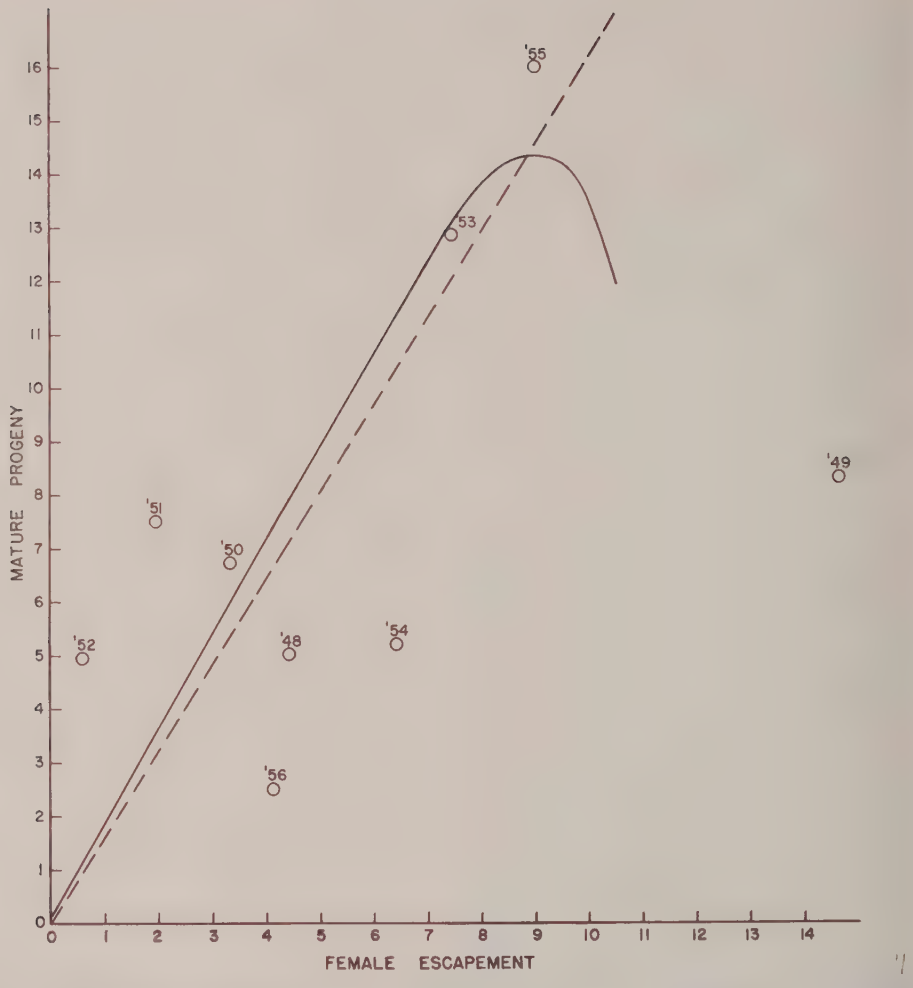

FIGURE 3.—Estimated reproduction curve for Pelican Creek, based on data from 1948 to 1956—expressed in thousands of fish. The broken line indicates the level at which replacement of parental stock occurs.

assumption that high spring temperatures would cause rapid snow melting with ensuing flooding of redds, and that high summer temperatures could conceivably cause fry mortality from exessive water temperatures. The assumptions are not unreasonable, as Pelican Creek has many thermal springs (Cope, 1957a), and warm weather during the spawning migration frequently causes flooding at the Pelican Creek trap and occasionally at the Chipmunk Creek trap. Correlation between year-class strength and mean air temperatures during the main spawning period (June–July) was not significant for Pelican Creek ($r=0.325$, $d.f.=7$).

Temperature data not presented in this paper indicate that water temperatures were highest during July in Pelican Creek, which is the major incubation period in that stream. Correlation between mean air temperature during July and year-class

strength was also not significant ($r=0.049$). The influence of air temperature is probably obscured by more prominent factors such as stream flow, which is partially controlled by air temperatures during the spawning period.

Water levels

Excessive stream flow can affect production of salmonids by decreasing the efficiency of egg deposition, by erosion or siltation of the redds, or by actual destruction of fry (Gangmark and Bakkala, 1960). Low water levels may limit spawning in the most favorable areas or cause exposure of redds. As stream flow data were not available, lake water levels were used as an index of stream flow into the lake. Yellowstone Lake is fed by a large tributary system, and fluctuations in lake level should be representative of tributary flow. In the summer of 1960 the trend in lake levels was similar to Pelican Creek water levels, but lagged approximately a week behind the stream. No data were available to compare Chipmunk Creek stream flow with lake levels.

The nature of the spring runoff in Pelican Creek suggests that stream flow could easily influence trout production. Pelican Creek is noted for its high spring runoff, which commonly flows over the trap and necessitates continual cleaning of the weir. In high-water years large trees are often flushed downstream and deposited against the weir. The Pelican Creek spawning migration usually commences in earnest about May 18, and young-of-the-year begin emerging from the gravel in the middle of July. Allowing 1 week for the fish to reach the spawning sites, the incubation period starts about May 25 and ends by July 31. The wide range in the time by which 50 percent of the run migrated upstream suggests that the incubation period varies slightly from year to year and that more accurate comparisons with year-class strength could be made if these variations were considered. The spawning runs usually start and end about the same time each year, even though variations occur in the time by which one-half of the run passes upstream. The part of the run which produces the year class is also not known. Thus, lake water levels from June 1 to July 31 were used in Pelican Creek comparisons, as this period covered most of the spawning and incubation in all years.

Pelican Creek data suggested a curvilinear relation between mean water levels and year-class strength from 1948 to 1956, and estimates of year-class strength were transformed to base–10 logarithms for comparison (fig. 4). Approximately 91 percent of the variation in production in Pelican Creek was associated with mean lake water levels during June and July ($r=-0.955$, significant at the 1-percent level). Assuming a linear relation between water levels and year-class-strength, correlation was only slightly lower ($r=-0.904$) and was still highly significant. Production was highest at low water levels and decreased as water level increased. A negative relation between water levels and production is uncommon, although Vernon (1958) found such a relation in pink salmon of the Fraser River. Poor production in flood years is to be expected, but drought years usually have low production also (Rounsefell, 1958; Wickett, 1958). Water levels in Pelican Creek apparently never became sufficiently low during the study period to be detrimental to production.

Differences between mean June and mean July water levels with the sign ignored were compared with year-class estimates for Pelican Creek to determine whether fluctuations in water level within the spawning period were influencing year-class strength. The correlation was not significant ($r=-0.278$, $d.f.=7$). Mean stream flow during spawning and incuba-

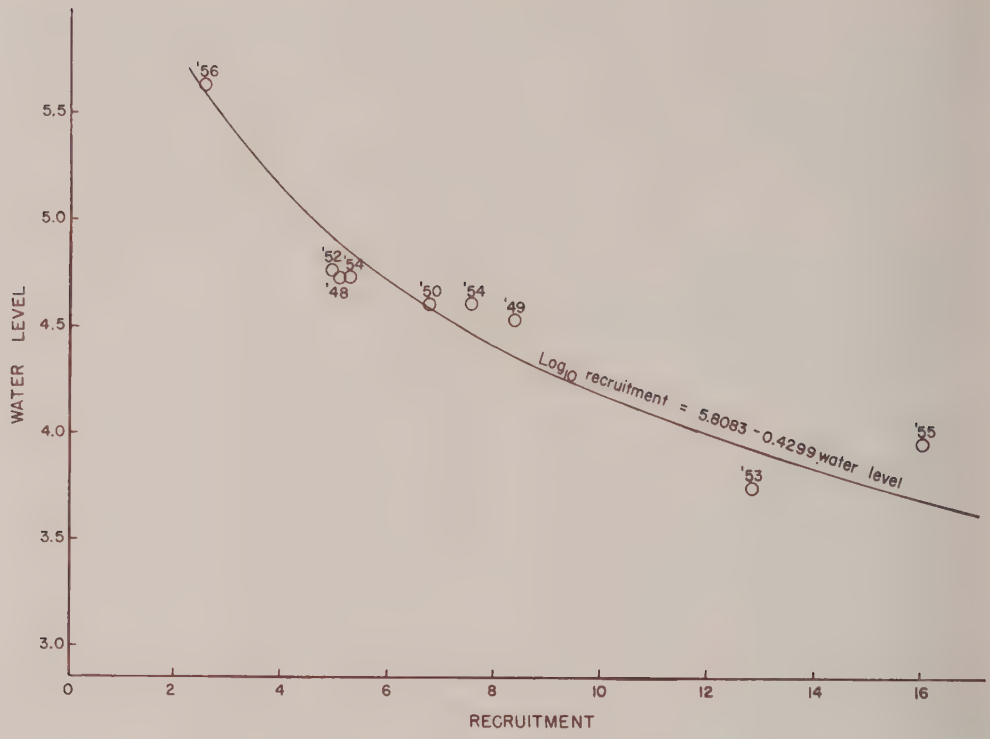

FIGURE 4.—Mean June-July water levels (feet) of Yellowstone Lake in relation to recruitment to the Pelican Creek spawning runs from each year class—expressed in thousands of fish.

tion was apparently the major controlling factor rather than the degree of fluctuation about the mean flow.

Combined effects

More variation in year-class strength could be explained when several factors were compared simultaneously. Frequently interaction between two factors masks individual effects on production. The effects of water levels, escapement, temperature, and timing of the runs on production were further analyzed by multiple regression analysis to determine whether two or more variables were interacting.

Data from 1948 to 1956 on female escapement, mean June-July water levels, and differences in mean June and mean July water levels were analyzed simultaneously with Pelican Creek year-class strength. As air temperature was believed to be influencing water conditions, it was not included in the analysis. Data on timing of the runs were not available for some years, and that variable was not included. Multiple correlation between year-class strength and escapement, water levels, and water fluctuations was significant at the 5-percent level ($R=0.925$, $d.f.=5$). The three factors were associated with approximately 77 percent of the variation (R^2_A) in Pelican Creek production.

When estimates of year-class strength were transformed to base-10 logarithms and were then correlated with escapement, mean water levels and water-level fluctuations, the correlation was significant at the 1-percent level ($R=0.980$)

and the amount of the variance related to these factors increased to 93.8 percent. Elimination of escapement from the multiple regression, and comparison of year-class strength with water levels and water fluctuations, reduced the correlation to 0.978, but the amount of variation in year-class strength (R^2_A) associated with these two measurements of water condition was 94.3 percent. This correlation was also significant at the 1-percent level.

A series of residuals (Ricker, 1958) was used to determine whether timing of the runs could account for the remaining variations in year-class strength after the effects on year-class strength of mean water level and water-level fluctuations were removed. The use of residuals was considered legitimate, as the effect of water levels on production has been reported frequently in the literature, and the concurrent fluctuations in water level and production in Pelican Creek strongly suggest that a causal relation exists. The residuals are the positive and negative deviations from the regression line which expresses the relation between log-10 year-class strength, mean June-July water levels and the difference in mean June and mean July water levels. They indicate the amount of error in the estimates for the years considered. Computation of the residuals for Pelican Creek is presented in appendix B. Correlation between the residuals and timing of the runs was not significant ($r=-0.410$, $d.f.=5$). Hence, the conclusion that timing of the runs was of little importance in controlling Pelican Creek production during the study period appears to be correct.

There is some suggestion that part of the high correlation between water conditions and year-class strength was actually due to escapement, as two years of good production (1953, 1955) had large escapements as well as low water levels. This relation between water levels and escapement is indicated by a correlation of 0.404 (not significant). Figures 3 and 4 show that both June–July water levels and year-class strength were essentially the same in 1948, 1952, and 1954, but that the 1952 escapement (613 females) was less than 10 percent of the 1954 escapement and less than 14 percent of the 1948 escapement. Water levels definitely appeared to be a stronger influence than escapement, at least to the extent that high escapement could not produce a strong year class unless favorable water conditions existed.

Further clarification of the relation of water conditions and escapement to year-class strength is obtained by adjusting year-class abundance to average conditions of water level and water fluctuation. The procedure used for adjusting year-class abundance is as follows. The residuals previously obtained by removing the effect of mean water levels and water-level fluctuations were added to the mean logarithmic value of year-class strength and the antilogs computed (appendix C). The adjusted estimates of year-class strength were then plotted against female escapement (fig. 5). The resulting reproduction curve, drawn in freehand, is a Beverton-Holt type curve (Beverton and Holt, 1957, p. 51) illustrating a population in which year-class abundance is independent of parent escapement over a wide range. Production in Pelican Creek is probably not as independent of spawner escapement as indicated by this curve, but is undoubtedly controlled more by water conditions within the observed range of spawner numbers than by size of the escapement. Under suitable water conditions the reproduction curve may be quite similar to the curve in figure 3.

Chipmunk Creek

There was less evidence of a relation between parent and progeny numbers in the Chipmunk Creek spawning runs ($r=0.230$, $d.f.=6$) than in the Pelican

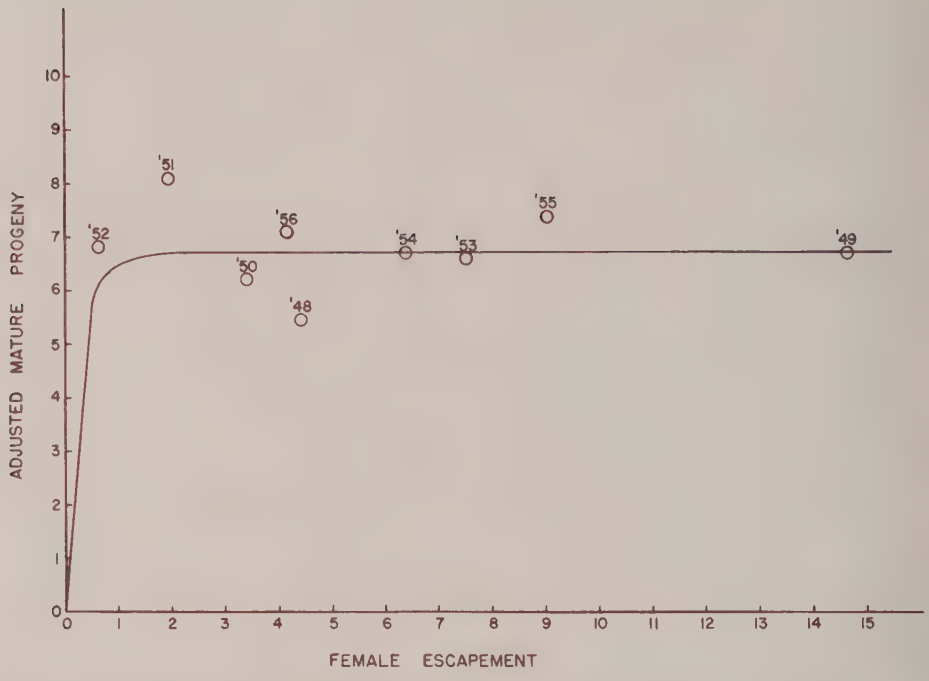

FIGURE 5.—Pelican Creek reproduction curve with number of progeny adjusted to average water conditions—expressed in thousands of fish.

Creek runs. This lack of significant correlation is apparent from the scatter diagram of Chipmunk Creek escapement and number of fish of age groups III, IV, and V returning from each year class (fig. 6). Recruitment to ensuing runs of progeny from approximately the same number of female spawners in six different years varied from 2,729 to 11,524 fish. Shape of the reproduction curve was not apparent from the data due, in part, to the limited range in number of spawners. The regression line shown was fitted by least squares. The broken diagonal line is based on the average sex ratio of 1.48 females per male for Chipmunk Creek spawners (Ball and Cope, 1961) and indicates the line upon which the parental stock just replaces itself. Escapement to the right of the diagonal line, as indicated by 1950 data, failed to produce equal numbers of progeny. The 1950 escapement containing 2,628 females had a return of only 2,729 progeny, while approximately 4,438 fish of both sexes were needed to maintain the same population density. In 1946 the parental stock just replaced itself. The desirable abundance level of female spawners for Chipmunk Creek appears to be about 2,724 fish, the average number for the eight years examined. This figure represents a spawning run of approximately 4,600 fish based on the average sex ratio of previous runs.

Correlation between year-class strength and mean air temperature during the June-July spawning period was also not significant for Chipmunk Creek ($r=0.100$, $d.f.=6$). There was no relation ($r=0.093$) between year-class strength and mean air temperature during August, the month when stream temperatures were highest in Chipmunk Creek.

Timing of the spawning runs was associated with Chipmunk Creek production, as 45 percent ($r=-0.673$, $d.f.=6$) of the variation in year-class strength was associated with timing although the correlation was not high enough to be significant. From May 28 to July 8, the earlier that 50 percent of the run moved upstream, the greater was the production from Chipmunk Creek. The correlation was not related to the bimodal nature of the Chipmunk Creek runs because the time by which 50 percent of the run had moved upstream did not coincide with the first peak in the number of spawners. Data presented later suggest that the correlation resulted from both variables being influenced by water levels.

Chipmunk Creek averaged 12.7 days later than Pelican Creek for 50 percent of the run to be upstream for the 6 years in which data on timing of the runs were available (table 2). For purposes of analysis the spawning and incubation period was assumed to be 2 weeks later in this stream than in Pelican Creek. There appeared to be no justification from plotted data to transform year-class estimates to logarithmic values, and actual estimates were used. Comparison of Chipmunk Creek year-class strength with mean lake water levels from June 15 to August 15 was not quite significant at the 5-percent level ($r=-0.667$, $d.f.=6$). Failure to obtain a higher correlation suggests either that lake water levels do not accurately represent Chipmunk Creek stream flow or that water level has less control over production in Chipmunk Creek than in Pelican Creek. A correlation, significant at the 5-percent level, between year-class strength and mean July lake levels ($r=-0.755$) indicates that the month of July may be the critical period for water levels in Chipmunk Creek

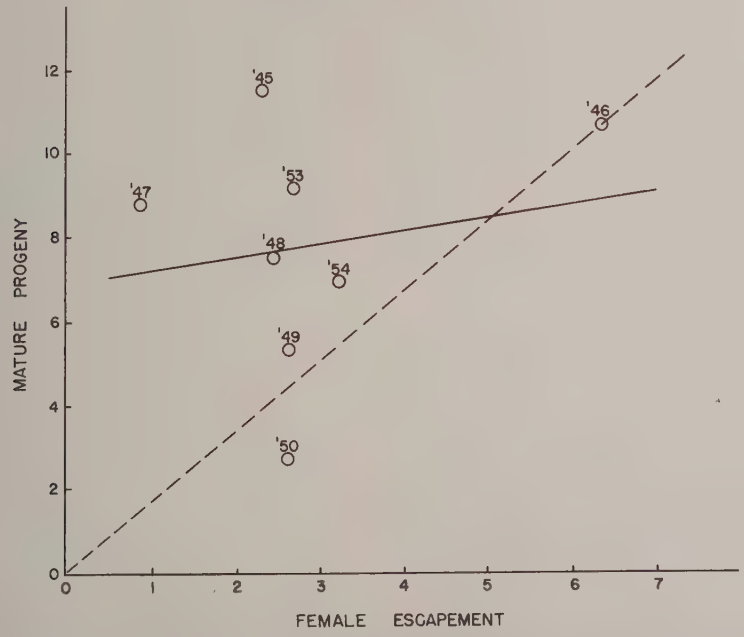

FIGURE 6.—Chipmunk Creek female escapement in relation to the year class it produced—expressed in thousands of fish. Line fitted by least squares. The broken line indicates the level at which replacement of parental stock occurs.

rather than the period from June 15 to August 15.

The amount of fluctuation in water levels within the Chipmunk Creek spawning period was expressed as the difference between mean water levels for the first month of the period (June 15 to July 15) and the second month (July 15 to August 15). The correlation was high but not significant ($r=-0.655$, $d.f.=6$).

Comparison of various combinations of factors with Chipmunk Creek year-class strength did not reveal any significant correlations:

Variables compared	*R*
Water levels, water fluctuations, escapement, timing of runs	0.834
Water levels, water fluctuations, escapement	.817
Water levels, water fluctuations, timing of runs	.799
Water levels, water fluctuations	.794

Mean water levels from June 15 to August 15 were used in this analysis because the 2-month period covered the time of major incubation in all years. Escapement and timing of the runs contributed little to the multiple correlation, even though timing was almost significantly correlated with year-class strength when compared alone ($r=-0.673$). Mean water levels from June 15 to August 15 and the difference in mean water levels between the first and second month of this period contributed most to the multiple correlation ($R=0.794$), but could still account for less than half of the variation in year-class strength ($R^2_A=0.483$).

A significant correlation between water levels and timing of the runs ($r=0.794$, $d.f.=6$) explains why more of the variation in year-class strength was not accounted for when both variables were considered together with year-class strength. Although water levels from June 15 to August 15 did not coincide exactly with time of the spawning runs, the high correlation suggests a causal relation between water levels and timing. Workers operating the fish traps in both Pelican and Chipmunk Creeks always expect an increase in the runs following a peak in stream water levels. Cope (1956) reported that diurnal fluctuations in stream temperature and water flow triggered upstream migration of spawners in Arnica Creek, another tributary to Yellowstone Lake. Stream discharge frequently influences the time of migration of spawning salmonids (Shapovalov and Taft, 1954), and artificial freshets have even been used to trigger spawning runs of Atlantic salmon (Hayes, 1953). Water levels in Chipmunk Creek influenced timing of the spawning runs as well as year-class strength.

PREDICTION OF FUTURE PRODUCTION

Recruitment to the fishery

Knowledge of factors associated with year-class strength is important for estimating future recruitment to the fishery. Stream flow during spawning appears to be the major factor controlling production in Pelican Creek and Chipmunk Creek although the actual means by which it accomplishes this control is not known. The method used for determining the effect on year-class strength of stream flow and other environmental factors introduced an unknown amount of bias which can be detected only by reference to future data. Hence, forecasts of future recruitment based on the observed correlations must be viewed with caution. Chipmunk Creek correlations were inadequate for prediction, but correlations between lake water levels and Pelican Creek production were sufficiently high that numerical estimates of year-class

strength can be calculated for this stream. The values obtained are estimates of the number of initial spawners to expect from a year class. As the fishery centers on fish of essentially the same age groups as found in the spawning runs, the estimates also provide an index of relative year-class strength in that portion of the lake fishery supported by fish from the stream. The estimates should be reliable in the future if our assumption that escapement is of secondary importance is correct and overfishing does not reduce spawning runs below the levels observed during this study.

Pelican Creek estimates are valuable because year-class strengths of Pelican Creek and the Fishing Bridge area fishery are similar, and the Fishing Bridge area accounts for over 60 percent of the total annual catch from Yellowstone Lake. It was necessary to use another method for estimating year-class strength to illustrate this similarity. The method used for spawning runs could not be applied to the fishery because the catch fluctuated widely from 1950 to 1959 and the size of the catchable population was not known. The el-Zarka (1959) method based on the relative contributions of two consecutive year classes was used (appendix D). Relative year-class strength estimates from Pelican Creek spawning runs and Fishing Bridge catch are significantly correlated ($r=0.825$, $d.f.=6$), and either can be used as an index of year-class strength for both. Samples from both areas indicated that 1949 and 1953 produced good year classes and that 1947, 1951, and 1954 produced poor year classes. Factors that control year-class strength in Pelican Creek obviously influence other spawning streams contributing to the Fishing Bridge area fishery. Hence, estimates of Pelican Creek year-class strength should also indicate the relative amount of recruitment to the fishery that can be expected from each year class.

The prediction equation for Pelican Creek utilizes the mean lake water levels during spawning and incubation and differences between mean water levels during this period. The equation is expressed as follows:

$$\hat{Y}=5.90487-0.42450X_1-0.18625X_2$$

where $\hat{Y}$ is $\log_{10}$ year-class strength expressed as the number of fish of age groups III and IV recruited to the spawning runs from year class, X_1 is the mean June–July lake level in feet, X_2 is the difference in feet between mean June and mean July lake levels.

Comparison of estimated year-class strength (geometric mean estimates) with empirical values indicates that the trend is very similar in most years (fig. 7). Estimated strength of the 1948 year class was 23 percent higher than the actual value. Error of the estimates in other years was less, but sufficient to indicate that estimates of future year-class strength must be accepted with due caution.

Recruitment of cutthroat to the Yellowstone Lake fishery commences in the third year of life (age group II) and is completed in the fifth year of life. The major contribution of each year class occurs during the fifth year of life at age IV (Bulkley, 1961). Thus, the 1961 fishery will draw mainly from the 1957 year class, and the 1962 fishery from the 1958 year class. Estimates of relative year-class strength from the above formula for 1957 and 1958 in Pelican Creek with 95-percent confidence limits are as follows: 1957, 7,121 (4,971–10,200); 1958, 14,910 (10,150–21,900). Spawner numbers were adequate in these two years, as female escapement was approximately 10,414 fish in 1957 and 4,320 fish in 1958. The confidence limits are so wide partly because they are set about a single value of Y instead of the mean Y value for the given values of X_1 and X_2, but they also indicate the large amount of possible

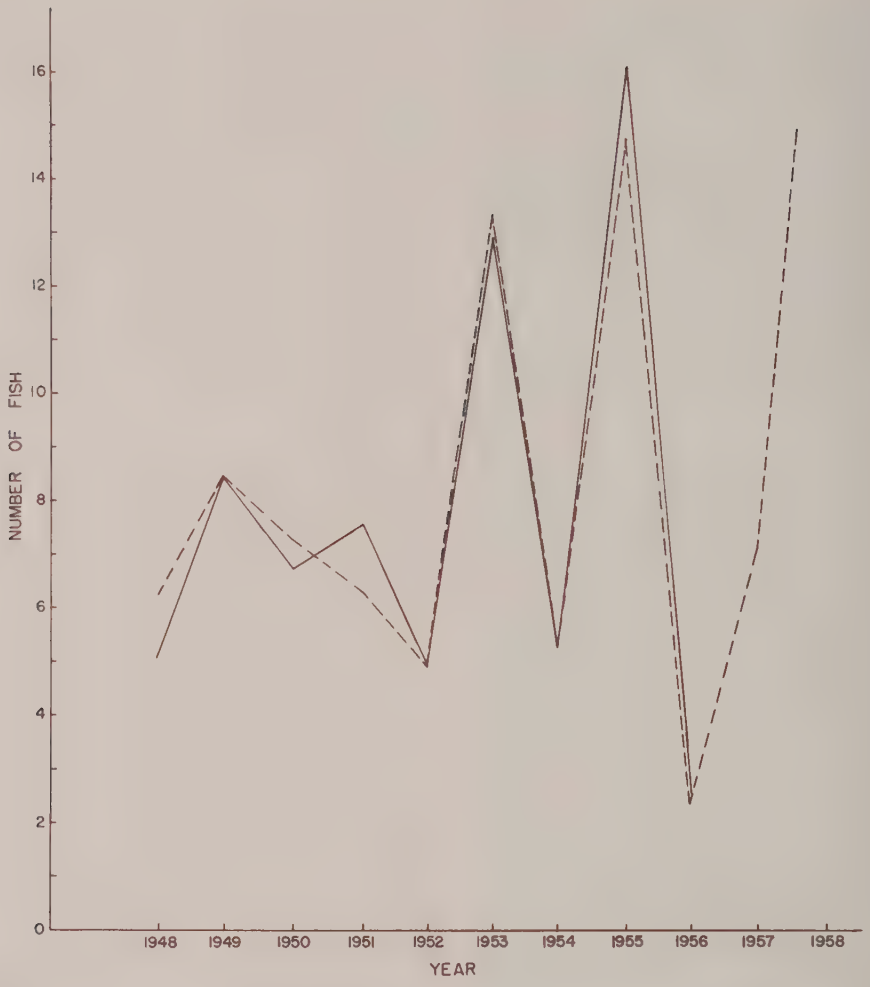

FIGURE 7.—Recruitment to Pelican Creek spawning runs by year class (solid line) and estimated recruitment) recruitment (broken line) from 1948 to 1958—expressed in thousands of fish.

error in the estimates. The 1957 year class was below average strength when compared with data from previous years (fig. 7). This year class was also heavily exploited at age III in 1960[2] so that relatively few fish of age group IV, will be available to the 1961 Fishing Bridge area fishery. The 1958 year class was very strong, and fish of age group III should be relatively abundant in the 1961 fishery. Adequate stocks of fish of age group IV will be available for the fishery in 1962 providing the 1958 year class is not overexploited at age III in 1961.

Numerical estimates of Chipmunk Creek year-class strength are subject to considerable error because only half of the variation in year-class strength can be attributed to known factors. Present data indicate that good production can be expected if water levels are low and relatively stable during the incubation period and if spawner numbers are ade-

[2] See footnote 1 on p. 3.

quate. Weak year classes will be produced in years when lake water levels are high or fluctuate widely during June and July, even if spawning runs are large. More accurate data are necessary on Chipmunk Creek stream flow and related variables before numerical estimates of year-class strength can be made.

Strengthening of weak year classes

Although the Yellowstone Lake fishery can produce an excellent yield from natural reproduction alone, knowledge of probable year-class abundance at the time the year class is produced provides an opportunity, if desired, to strengthen weak year classes by stocking. As strength of the year class apparently is determined during the spawning and incubation period, supplemental planting of fry after this period would compensate for low survival in years of high water. There is little doubt that fry planting in tributary streams of Yellowstone Lake can be of great benefit.[3] Year classes from 1940 to 1944 in Pelican Creek were entirely the result of fry [4] planting (no escapement allowed), and these year classes were stabler and stronger, on the average, than year classes produced from natural reproduction. It should be noted, however, that the two strongest year classes (1953 and 1955) produced in Pelican Creek from 1942 to 1956 [5] were entirely the result of natural reproduction. In years of favorable water conditions, planting would be unnecessary so long as escapement was adequate.

Data in table 3 provide an index for determining whether planting of fry would be desirable in any given year. Pelican Creek spawners failed to replace themselves with equal numbers of recruits in 1948, 1949, 1954, and 1956. In 1948, 1954, and 1956 mean June–July lake water levels were 4.75 feet or higher, well above the 9-year average of 4.60 feet for this period. In 1949 the mean lake water level was only 4.53 feet, but the escapement of 14,591 females was the largest number ever recorded. Favorable water levels in 1949 should have allowed adequate replacement of spawning stocks. Failure of the run to replace itself is attributed to excessive spawner density in that year. With the high fishing pressure in recent years, we doubt whether excessive escapement will be a future problem. The fact that mean lake levels during spawning were 4.75 feet or higher in three of the four years of insufficient replacement leads us to conclude that very low natural production can be ex-

[3] See footnote 1 on p. 3.

[4] Some fish were classified as 1-inch fingerlings in the hatchery records.

[5] See footnote 1 on p. 3.

TABLE 3.—*Spawner and recruitment numbers for Pelican and Chipmunk Creeks with related lake water levels*

Year-class	Mean June–July water level	Mean July water level	Pelican Creek			Chipmunk Creek		
			Female escapement	Recruitment, both sexes	Recruitment needed to replace stock[1]	Female escapement	Recruitment, both sexes	Recruitment needed to replace stock[2]
	Feet	*Feet*						
1945		4.24				2,331	11,524	3,906
1946		3.75				6,350	10,665	10,640
1947		4.62				841	8,838	1,409
1948	4.75	4.49	4,418	5,032	7,109	2,449	7,500	4,104
1949	4.53	4.38	14,591	8,377	24,056	2,650	5,286	4,441
1950	4.61	5.34	3,381	6,755	5,440	2,628	2,729	4,404
1951	4.72		1,969	7,569	3,168			
1952	4.77		613	4,985	986			
1953	3.74	4.27	7,475	12,863	12,027	2,711	9,184	4,543
1954	4.75	5.19	6,438	5,267	10,359	3,237	6,921	5,424
1955	3.95		9,030	16,023	14,529			
1956	5.61		4,166	2,503	6,703			

[1] Based on average sex ratio of 1.64 females per male.

[2] Based on average sex ratio of 1.48 females per male.

pected in years when this water condition occurs. Supplemental fry planting should significantly increase production in Pelican Creek in these years.

According to available data, Chipmunk Creek spawners failed to replace themselves only in 1950 when the mean July lake level (5.34 feet) was the highest recorded. The next highest mean July level was 5.19 feet in 1954, when the spawning run more than replaced itself. The critical July water level for Chipmunk Creek production must lie between 5.19 and 5.34 feet. Supplemental stocking of fry would appear to be beneficial in this stream whenever mean July lake level exceeds 5.19 feet.

Reliable forecasts of lake water levels are essential in a management program based on water conditions where fish planting is desirable in some years and not in others; preparations must be made in advance for the taking of spawn and for hatchery operations. Since 1937 the U.S. Soil Conservation Service, in cooperation with the U.S. National Park Service, has conducted a snow survey at several points in the Yellowstone Lake drainage. By relating snow survey measurements taken over a period of years to spring-summer runoff during the same period, relations have been developed which make it possible to forecast seasonal runoff several months in advance of occurrence. Snow survey data from 1937 to 1960 were utilized by the Soil Conservation Service at Bozeman, Mont., to compute formulas for accurately predicting Yellowstone Lake water levels in June and July as early as March 1 of the same year. Accuracy of the forecasts is influenced by the amount of precipitation during the spring and early summer and by air temperatures during the melt season. The forecasts are sufficiently accurate to determine whether water conditions will be suitable for cutthroat reproduction and whether fry stocking would be advisable.

Forecasts of Yellowstone Lake water level during 1961 based on snow conditions as of March 1, 1961, are as follows: [6] The expected mean June-July lake water level will be approximately 3.94 feet, well below the level where supplemental planting is recommended (4.75 feet). Expected mean June–July lake water level based on snow conditions as of April 1, 1961, is 3.87 feet, slightly lower than the March 1 estimate but essentially the same. Conditions for trout reproduction in Pelican Creek should be excellent in 1961. The mean July lake water level is predicted to be 4.07 feet above datum based on March 1 snow conditions and 4.05 feet according to snow conditions on April 1.[7] Favorable water conditions are also indicated for Chipmunk Creek production if runoff is gradual. These water forecasts suggest that fry stocking is unnecessary in 1961 and that a strong year class will be produced, but inadequate spawner escapement may seriously reduce production. A very low escapement is expected in both streams in 1961 owing to the heavy overfishing in 1959 and 1960 in Yellowstone Lake [8] and to the weak 1957 year class in Pelican Creek. If spawner escapement falls below previous levels, the number of spawners may become the major factor limiting production. Data collected in 1961 and ensuing years should cast additional light on the relation of spawner escapement and water levels to year-class strength and allow for the refinement of the prediction formulas.[9]

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[6] Personal correspondence from Mr. Ashton R. Codd, Snow Survey Supervisor, Soil Conservation Service, Bozeman, Mont.

[7] After 1961 forecasts of Yellowstone Lake water conditions based on snow condition on February 1, March 1, and April 1 will appear in "Snow Survey and Water Supply Forecasts for Montana and Northern Wyoming (Upper Missouri and Upper Columbia River Basins)." U.S. Department of Agriculture, Soil Conservation Service, and Montana Agricultural Experiment Station, Bozeman, Mont.

[8] See footnote 1 on p. 3.

[9] The actual number of initial spawners from the 1957 year class which entered the 1960 and 1961 Pelican Creek runs was 8,643, which was 21 percent above the predicted number but well within the established confidence limits.

SUMMARY

Large fluctuations in year-class strength of cutthroat trout occurred from 1948 to 1956 in Pelican Creek and from 1945 to 1954 in Chipmunk Creek. Recruitment to the spawning runs was used as an index of year-class strength.

Recruitment was related to female escapement in Pelican Creek, although the exact shape of the reproduction curve was obscured by environmental influences. Correlation between female escapement and recruitment of the year class was not significant ($r=0.480$). The 1949 run of 14,591 female spawners appeared to be an excessive escapement for Pelican Creek. Maximum production should be obtained from approximately 9,000 females if environmental conditions are suitable. The date by which 50 percent of the Pelican Creek run moved upstream was not a critical factor in production ($r=0.115$). Mean air temperature during the spawning period ($r=0.325$) and during the month of maximum stream temperature ($r=0.049$) were also not major factors.

Mean lake level during June and July which was used as an index of stream flow was strongly correlated with Pelican Creek year-class strength ($r=-0.955$). Variation in year-class strength associated with mean water levels and the difference in water levels during spawning amounted to 94.3 percent ($R=0.978$). The analyses indicate that adequate escapement cannot produce an abundant year class unless water levels are favorable.

Chipmunk Creek year-class strength appeared to be completely independent of escapement ($r=0.230$) within the range of 841 to 6,350 female spawners. The average escapement of 2,724 females appeared to be adequate. The time by which 50 percent of the run moved upstream was correlated with Chipmunk Creek year-class strength ($r=-0.673$), but this relation was not causal because water levels influenced both timing of the runs and year-class strength. Air temperatures during the spawning period ($r=0.100$) and during August when stream temperature was highest ($r=0.093$) were not critical factors. Multiple correlation between year-class strength, mean water level, and fluctuations in water levels during the incubation period showed that less than 50 percent of the variation in year-class strength ($R=0.794$) was associated with these two factors.

Recruitment to the Pelican Creek spawning runs from the 1957 and 1958 year classes was estimated to be 7,121 and 14,910 fish respectively from the formula $\hat{Y}=5.90487-0.42450X_1-018625X_2$. Year-class strength in Pelican Creek and the Fishing Bridge area fishery are similar. The number of age IV fish in the fishery will be well below average in 1961 and above average in 1962 unless overfishing removes the fish at a younger age. No predictions were made from Chipmunk Creek correlations, but good year classes can be expected if water levels are low and stable during spawning and if escapement is adequate.

Stocking of fry has been successful in past years, which indicates that the large fluctuations in year-class strength can be leveled off by fry-planting in years of unsuitable water conditions. Stocking is recommended in Pelican Creek in years when mean June–July lake level is above 4.75 feet and in Chipmunk Creek when mean July lake level is above 5.19 feet. Acceptable forecasts of lake water levels during incubation, to determine whether stocking is necessary in any given year, can be made as early as March 1 from snow survey data. The forecast for 1961 indicates that water levels should be excellent for trout production if runoff is gradual.

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Appendix A—WATER LEVELS AND AIR TEMPERATURE DATA ON YELLOWSTONE LAKE

TABLE A–1.—*Yellowstone Lake mean water levels and mean air temperatures, 1945 to 1956*

Factor and period	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956
Water level (feet):												
June 1–15	3.65	3.54	3.70	4.61	4.31	3.10	4.02	4.67	2.24	3.96	2.84	5.61
16–30	5.09	4.16	4.57	5.39	5.05	4.67	4.86	5.88	4.18	4.65	4.22	6.38
July 1–15	4.11	4.01	4.73	4.94	4.77	5.59	5.09	4.54	4.52	5.45	4.34	5.70
16–31	4.36	3.49	4.51	4.03	3.98	5.08	4.89	4.00	4.01	4.92	3.88	4.73
August 1–15	3.74	2.83	3.85	3.22	3.19	4.05	4.53	3.35	3.25	3.85	3.29	3.81
Air temperature (°F.):												
June 1–30	43.1	48.8	43.6	50.2	46.8	44.8	41.7	48.7	46.2	43.7	45.3	54.0
July 1–31	51.0	56.2	55.8	58.0	54.1	50.8	55.4	52.0	57.1	61.8	56.3	55.6
August 1–31	53.0	53.1	52.6	59.0	54.4	51.6	52.9	52.8	54.1	51.3	56.4	52.7

Appendix B—COMPUTATION OF RESIDUALS

TABLE B–1.—*Calculations used to compute residuals for Pelican Creek year-class strength with effect of annual and monthly water-level fluctuations removed*

Year	Number of fish in age groups III and IV returning	Log_{10} Y	Mean June-July water levels X_1	Difference between mean June and mean July water levels X_2	Calculated [1] $\hat{Y}$	Residuals $Y-\hat{Y}$
1948	5,032	3.70174	4.75	0.51	3.79352	−0.09178
1949	8,377	3.92309	4.53	0.30	3.92602	−0.00293
1950	6.755	3.82963	4.61	1.45	3.86413	−0.03450
1951	7.569	3.87904	4.72	0.55	3.79880	0.08024
1952	4.985	3.69767	4.77	1.01	3.69191	0.00576
1953	12,863	4.10934	3.74	1.06	4.11984	−0.01050
1954	5,267	3.72156	4.75	0.88	3.72461	−0.00305
1955	16,023	4.20474	3.95	0.33	4.16665	0.03809
1956	2,503	3.39846	5.61	0.78	3.37816	0.02030

[1] Calculated from the formula $\hat{Y}=5.90487-0.42450X_1-0.18625X_2$

Appendix C—ADJUSTED ESTIMATES OF PELICAN CREEK YEAR-CLASS STRENGTH

TABLE C–1.—*Calculation of year-class strength for average June-July lake water levels and average change in mean water levels from June to July*

1 Year	2 Log residuals	3 Female escapement	4 Log adjusted numbers [1]	5 Adjusted year-class strength [2]
1948	−0.09178	4,418	3.73769	5,457
1949	−0.00293	14,591	3.82654	6,707
1950	−0.03450	3,381	3.79497	6,237
1951	0.08024	1,969	3.90971	8,123
1952	0.00576	613	3.83523	6,843
1953	−0.01050	7,475	3.81897	6,591
1954	−0.00305	6,438	3.82642	6,705
1955	0.03809	9,030	3.86756	7,371
1956	0.02030	4,166	3.84977	7,076

[1] Mean $\log_{10}$ year-class strength=3.82947. Column 4=3.82947 plus column 2.
[2] Antilog of column 4.

Appendix D—RELATIVE YEAR-CLASS STRENGTH OF PELICAN CREEK AND FISHING BRIDGE CATCH

The method of el-Zarka (1959) was used to obtain estimates of relative year-class strength to compare Pelican Creek fish with the catch at Fishing Bridge dock. This method is based on the relative contributions to the catch or spawning runs of two consecutive year classes. Only age groups III, IV, and V were used for the comparison, because age group II is not present in the spawning runs, and the older age groups are not always well represented in the catch. Data from table D–1 will be used to illustrate the method. The 1947 year class at Pelican Creek in its fourth year of life comprised 4.6 percent of the 1950 spawning run in that stream, 55.4 percent of the 1951 run in its fifth year of life, and 22.0 percent of the 1952 run in its sixth year of life. Sum of the three percentages is 82.0 percent. The 1948 year class in comparison contributed at the same ages; 2.5 percent of the 1951 run, 60.3 percent of the 1952 run, and 29.6 percent of the 1953 run. Total for the 1948 year class was 92.4 percent. The percentage difference in strength of the two year classes was then determined in the following manner:

$$\frac{2\ (82.0-92.4)\times 100}{82.0+92.4}=11.9$$

Hence, the 1948 year class was approximately 11.9 percent larger than the 1947 year class. Comparisons and calculations used to rank all year classes are summarized in table D–2. The percentage differences between years were first adjusted to give the relative position of each year class in the series. This adjustment was made by arbitrarily assigning year class 1947 a value of 0.0 and adding percentage differences of each succeeding comparison to it. The resulting series of figures was then adjusted to a mean of 0.0 for all year classes to obtain the final rankings presented in the right-hand column of table D–2.

TABLE D–1.—*Partial age composition and year classes of Yellowstone Lake cutthroat*

[Data from Pelican Creek spawning runs and catch at Fishing Bridge dock, 1950–59]

Year of capture	For year class of—							
	1947	1948	1949	1950	1951	1952	1953	1954
1950:								
Age group	III							
Percentage:								
Pelican Creek	4.6							
Fishing Bridge	13.1							
1951:								
Age group	IV	III						
Percentage:								
Pelican Creek	55.4	2.5						
Fishing Bridge	34.0	13.5						
1952:								
Age group	V	IV	III					
Percentage:								
Pelican Creek	22.0	60.3	14.3					
Fishing Bridge	23.4	39.2	30.9					
1953:								
Age group		V	IV	III				
Percentage:								
Pelican Creek		29.6	58.3	8.6				
Fishing Bridge		35.3	30.8	21.3				
1954:								
Age group			V	IV	III			
Percentage:								
Pelican Creek			37.0	55.0	3.4			
Fishing Bridge			39.3	30.1	18.8			
1955:								
Age group				V	IV	III		
Percentage:								
Pelican Creek				32.4	58.2	6.5		
Fishing Bridge				41.3	26.9	20.1		
1956:								
Age group					V	IV	III	
Percentage:								
Pelican Creek					32.4	59.7	5.5	
Fishing Bridge					33.5	43.0	18.4	
1957:								
Age group						V	IV	III
Percentage:								
Pelican Creek						26.0	71.3	1.6
Fishing Bridge						30.8	53.5	12.3
1958:								
Age group							V	IV
Percentage:								
Pelican Creek							27.6	68.7
Fishing Bridge							38.1	46.3
1959:								
Age group								V
Percentage:								
Pelican Creek								23.3
Fishing Bridge								17.4

TABLE D–2.—*Data employed in determination of relative strength of year classes 1947 to 1954 of Yellowstone Lake cutthroat in Pelican Creek spawning runs and the catch at Fishing Bridge dock*

[Age groups III, IV, and V only]

Year-classes compared	Sum for first year	Sum for second year	Mean	Difference	Percentage difference between years	Relative strength of first year	Final rank of first year
Pelican Creek:							
1947–1948	82.0	92.4	87.2	10.4	11.9	0.0	−14.9
1948–1949	92.4	109.6	101.0	17.2	17.0	11.9	−3.0
1949–1950	109.6	96.0	102.8	−13.6	−13.2	28.9	14.0
1950–1951	96.0	94.0	95.0	−2.0	−2.1	15.7	0.8
1951–1952	94.0	92.2	93.1	−1.8	−1.9	13.6	−1.3
1952–1953	92.2	104.4	98.3	12.2	12.4	11.7	−3.2
1953–1954	104.4	93.6	99.0	−10.8	−10.9	24.1	9.2
1954						13.2	−1.7
Fishing Bridge:							
1947–1948	70.5	88.0	79.3	17.5	22.1	0.0	−22.2
1948–1949	88.0	101.0	94.5	13.0	13.7	22.1	−0.1
1949–1950	101.0	92.7	96.8	−8.3	−8.6	35.8	13.7
1950–1951	92.7	79.2	86.0	−13.5	−15.7	27.2	5.1
1951–1952	79.2	93.9	86.6	14.7	17.0	11.5	−10.7
1952–1953	93.9	110.0	102.0	16.1	15.8	28.5	6.4
1953–1954	110.0	76.0	93.0	−34.0	−36.5	44.3	22.2
1954						7.8	−14.4

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